PUB-NO: EP000887569A2

DOCUMENT-IDENTIFIER: EP 887569 A2

TITLE: Method for setting up a superconducting bearing device

PUBN-DATE: December 30, 1998


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APPL-NO: EP98118588

APPL-DATE: July 17, 1991

PRIORITY-DATA: EP91111965A ( July 17, 1991) , JP18869390A ( July 17, 1990) , JP40326390A ( December 18, 1990)

INT-CL (IPC): F16C039/06

EUR-CL (EPC): F16C039/06


ABSTRACT:


CHG DATE=19990905 STATUS=C> The invention relates to a method for setting up a superconducting bearing device including a permanent magnet portion (3, 8, 11) mounted on a rotor (1) having a vertical axis of rotation and a Type II superconductor (2, 6, 7) disposed in the permanent magnet portion's magnetic

field, the permanent magnet portion (3, 8, 11) being provided on the rotor (1) so that rotation of the rotor (1) does not alter a magnetic flux's distribution about the axis of rotation of the rotor (1); the method comprises first disposing the rotor (1) at position with respect to the Type II superconductor (2, 6, 7) to permit magnetic flux from the permanent magnet to penetrate the Type II superconductor (2); thereafter moving the Type II superconductor to, and holding the Type II superconductor at a temperature for realizing a Type II superconducting state to pin all the penetrating magnetic flux as it is in the interior of the Type II superconductor (2); and thereafter removing mechanical support from the rotor. <IMAGE>

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 887 569 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
30.12.1998 Bulletin 1998/53

(51) Int. Cl.$^6$: F16C 39/06

(21) Application number: 98118588.7

(22) Date of filing: 17.07.1991

(84) Designated Contracting States:
DE FR GB

(30) Priority: 17.07.1990 JP 188693/90
18.12.1990 JP 403263/90

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
91111965.9 / 0 467 341

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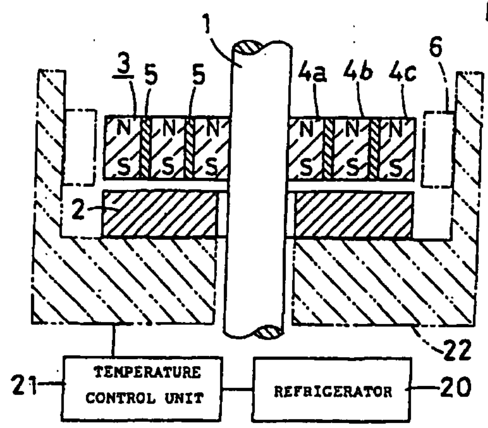
Remarks:
This application was filed on 011098 as a divisional application to the application mentioned under INID code 62.

# (54) Method for setting up a superconducting bearing device

(57) The invention relates to a method for setting up a superconducting bearing device including a permanent magnet portion (3, 8, 11) mounted on a rotor (1) having a vertical axis of rotation and a Type II superconductor (2, 6, 7) disposed in the permanent magnet portion's magnetic field, the permanent magnet portion (3, 8, 11) being provided on the rotor (1) so that rotation of the rotor (1) does not alter a magnetic flux's distribution about the axis of rotation of the rotor (1); the method comprises first disposing the rotor (1) at position with respect to the Type II superconductor (2, 6, 7) to permit magnetic flux from the permanent magnet to penetrate the Type II superconductor (2); thereafter moving the Type II superconductor to, and holding the Type II superconductor at a temperature for realizing a Type II superconducting state to pin all the penetrating magnetic flux as it is in the interior of the Type II superconductor (2); and thereafter removing mechanical support from the rotor.

FIG.3

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**Description**

BACKGROUND OF THE INVENTION

The present invention relates to a method for setting up a superconducting bearing device having incorporated therein a superconductor permitting penetration of a magnetic flux thereinto.

Superconducting bearing devices heretofore known include, for example, the one disclosed in Unexamined Japanese Patent Publication SHO 63-243523.

The superconducting bearing device disclosed includes a Type I superconductor, i.e., a superconductor preventing the penetration of magnetic flux perfectly to utilize the perfect diamagnetism of the superconductor. The device comprises a rotary shaft made of the superconductor and having its opposite ends fitted in a pair of recesses each of which is formed in a support member of magnetic material magnetized to one of the polarities, the rotary shaft being supported in a non-contacting position axially thereof.

With the known superconducting bearing device, the rotaty shaft is supported in a non-contacting position utilizing perfect diamagnetism as stated above and is therefore instable with respect to a direction orthogonal to the direction of repulsion, so that the support member for supporting each end of the rotary shaft must be machined to a shape surrounding the shaft end. Furthermore,between the shaft end and the support member, the portion opposed to the shaft end axially and radially of the shaft needs to be magnetized. Accordingly, the device is cumbersome to design and make.

A known superconducting bearing device (US 4,797,386) comprises a superconducting support body over which a magnet is levitated due to the Meissner effect when the system is cooled down to an appropriate temperature for realizing a Type II conducting state. The magnetic properties of the superconducting support body and the magnet are such that the value of $H_{cl}$ is exceeded in some regions of the superconducting support body by the field of the magnet to introduce vortices where the magnetic field penetrates the superconductor support body. Therefore a pinning force is created that stabilized the levitated magnet in a lateral direction.

For setting up this superconducting bearing device the magnet is either arranged above the superconducting support body when it is already cooled down or the magnet is rested in contact with the superconducting body prior to cooling. In the latter case the magnet will be levitated when a Type II superconducting state is realized. In both cases the levitation level depends on the magnetic characteristics of both the magnet and the superconducting support body.

Another bearing system employing a superconductor element (WO 90/03524) consists of a superconducting disc and a magnet shaped like a flat donut. When a Type II superconductor is used as a supporting body the magnetic field of the magnet partially penetrates into the bulk of the superconductor so that the magnet is simultaneously levitated over the superconductor and stabilized in a lateral direction by pinning the magnetic field lines developed in the superconductor owing to the partial penetration of the magnetic flux.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a method for setting up a superconducting bearing device so that the rotor is supported stably by the superconductor.

This object is achieved by the method of claim 1.

According to the present invention the rotor including the permanent magnet portion is disposed and mechanically supported in a predetermined position above the superconductor first. Thereafter the superconductor is cooled down to an appropriate temperature to pin all the penetrating magnetic flux therein. At least, the mechanical support is removed from the rotor to allow the rotor to move downward by its own weight to be held in a stable position at which gravity is in balance with a supportive magnetic force caused by the pinned flux.

Thus, the present invention makes it possible to trap a large quantity of magnetic flux released from the rotatable member, that penetrates into the superconductor when the superconductor is cooled to the superconducting state. Hence, the restraining action of the magnetic flux of the permanent magnet portion penetrating into the superconductor stably holds the magnet portion and the superconductor opposed to each other and spaced apart by a predetermined distance. In this state the rotatable member carrying the magnet portion can be rotated about the axis of the member. At this time, the external magnetic field acting on the superconductor of a no resistance to the rotation insofar as the magnetic flux distribution is uniform with respect to the axis of rotation and remains unchanged. Accordingly, the rotatable member can be supported by the superconductor in a non-contacting position radially and axially thereof when the magnet portion mounted on the rotatably member is merely positioned in place relative to the superconductor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation schematically showing a first superconducting bearing device used with the invention;

FIG. 2 is a side elevation schematically showing a second superconducting bearing device use with the invention;

FIG. 3 is a view in vertical section schematically showing a third superconducting bearing device used with the invention;

FIG. 4 is a view in vertical section schematically

showing a fourth superconducting bearing device used with the invention;

FIG. 5 is a view in vertical section schematically showing a fifth superconducting bearing device used with the invention;

FIG. 6 is a view in vertical section schematically showing a sixth superconducting bearing device used with the invention;

FIG. 7 is a view in vertical section schematically showing a seventh superconducting bearing device used with the invention; and

FIG. 8 is a view in vertical section schematically showing an eighth superconducting bearing device used with the invention.

DETAILED DESCRIPTION OF THE INVENTION

Throughout the drawings, like parts are designated by like reference numerals.

FIG. 1 schematically shows the main arrangement providing a first bearing device.

This device, i.e., a superconducting bearing device, comprises a solid cylindrical rotatable member 1, and a superconductor 2 in the form of a flat plate.

The rotatable member 1 in its entirety is a permanent magnet portion in the form of a single permanent magnet. The rotatable member 1 has one end magnetized to an N pole, and the other end magnetized to an S pole.

The superconductor 2 comprises a base plate which is prepared from a high-temperature superconducting material of the yttrium type of great pinning force, for example, $YBa_2Cu_3O_x$, and which contains normally conductive particles ($Y_2Ba_1Cu_1$) as uniformly mixed with the superconducting material. The superconductor 2 has properties to trap the magnetic flux released from the rotatable member 1 and penetrating thereinto.

The rotatable member 1 is disposed with its axis positioned horizontally and is rotatable about the axis without permitting alteration of the magnetic flux distribution around the axis despite the rotation.

The superconductor 2 is opposed to the rotatable member 1 and disposed at a position spaced apart from the member 1 by a distance permitting a predetermined quantity of magnetic flux of the member 1 to penetrate into the superconductor, the superconductor 2 further being so positioned that the rotation of the member 1 will not alter the distribution of penetrating magnetic flux. The superconductor 2 has its upper surface opposed to the outer peripheral surface of the rotatable member 1 and is positioned horizontally below the rotatable member 1 in parallel thereto.

When the bearing device is to be operated, the superconductor 2 is cooled by suitable cooling means and maintained in a superconducting state.

If the rotatable member 1 is merely disposed horizontally above the superconductor 2 as positioned horizontally in a superconducting state, only a small quantity of magnetic flux of the member 1 penetrates into the superconductor 2, so that the member 1 is merely levitated by a repulsive force due to the Meissner effect of the superconductor 2 and is not supported stably.

However, when the rotatable member 1 is disposed above the superconductor 2 in the vicinity thereof first and the superconductor 2 is thereafter cooled to the superconducting state, a large quantity of magnetic flux released from the rotatable member 1 penetrates into the superconductor 2 and is trapped in this state. Since the superconductor 2 contains pinning centers (e.g., normally conductive particles) as uniformly mixed with the superconducting material, the magnetic flux penetrating into the superconductor 2 becomes distrubuted also uniformly and is held trapped. Consequently, the rotatable member 1 is held levitated above the superconductor 2 and supported axially and radially with high stability.

When the rotatable member 1 as thus supported in a non-contacting position is rotated about its axis, the magnetic flux penetrating into the superconductor 2 offers no resistance to the rotation because the magnetic flux distribution around the axis remains unchanged despite the rotation. Further because the rotation involves no frictional resistance unlike sliding or rolling bearings, the rotatable member 1 is to rotate permanently, whereas the member is influenced by air resistance and geomagnetism in actuality and therefore comes to a halt eventually. Nevertheless, such resistance to rotation is very small for the bearing device and almost negligible.

If the rotatable member 1 as supported in the above non-contacting position is pushed in one direction with a force smaller than the pinning force, the member 1 shifts in this direction once, then shifts toward the original position, thus undergoing a swinging motion for some time, and thereafter comes to a stop at the original position. However, if the rotatable member 1 is pushed toward one direction with a force greater than the pinning force, the member 1 stops upon moving to a position to which it is forcibly shifted from the original position. Thus, the member 1 is restrained in the shifted position. This phenomenon occurs owing to the pinning force peculiar to the superconductor 2 of the foregoing structure.

If the magnetic flux of the rotatable member 1 is held pinned to the supercontactor 2 as described above, the rotatable member 1 will always be supported with good stability by a restraining action.

FIG. 2 schematically shows the main portion of another superconducting bearing device.

This second device is the same as the first device with respect to the structure and arrangement of the superconductor 2. The rotatable member 1, although the same as the one included in the first device, is disposed above the superconductor 2 with its axis of rota-

tion positioned vertically. The upper surface of the superconductor 2 is opposed to the lower end face of the rotary member 1. With the exception of this feature, the second device is the same as the first.

With the second device, the rotatable member 1 is also supported as levitated above the superconductor 2 as in the case of the first embodiment.

In the foregoing two embodiments, the arrangement of the rotatable member 1 and the superconductor 2 may be inverted. In other words, the rotatable member 1 may be disposed below the lower surface of the superconductor 2 in proximity to the superconductor 2. The rotatable member 1 is then supported as levitated as if being suspended from the superconductor 2. Alternatively, if the rotatable member 1 is opposed, as positioned obliquely, to the superconductor 2, the member 1 is held levitated in the oblique position.

FIG. 3 schematically shows the main portion of a third superconducting bearing device.

This bearing device comprises a rotatable member 1 in the form of a vertical shaft, and a superconductor 2. A permanent magnet portion 3 in the form of a horizontal disk is mounted on the rotatable member 1 concentrically therewith, and the superconductor 2 is opposed to the lower end face of the magnet portion 3 and spaced apart therefrom axially of the rotatable member 1. The superconductor 2 is in the form of a disk having a bore; and the rotatable member 1 extends through the bore with a clearance formed in the bore around the member 1.

The permanent magnet portion 3 is in the form of an integral assembly and comprises a plurality of annular permanent magnets 4a, 4b, 4c arranged at a spacing radially of the member 1, and a nonmagnetic material 5 interposed therebetween. The portion 3 is secured to the rotatable member 1. The upper and lower ends of each of the magnets 4a, 4b, 4c are magnetized to polarities opposite to each other, and all the magnets 4a, 4b, 4c are magnetized to the same polarity at their same ends. For example, the upper ends of all the magnets 4a, 4b, 4c are magnetized as N poles, and the lower ends thereof as S poles. The magnetic flux distribution around the axis of rotation is free of changes despite the rotation of the member 1.

The superconductor 2 has the same properties as the one included in the first embodiment and is disposed at a position spaced apart from the magnet portion 3 by a distance permitting a predetermined quantity of magnetic flux of the portion 3 to penetrate thereinto and which will not permit the rotation of the member 1 to alter the distribution of penetrating magnetic flux.

A cooling case 22 which is cooled by a refrigerator 20 or the like via a temperature control unit 21 is fixedly provided within a housing (not shown) for the bearing device. The superconductor 2 is fixed to the cooling case 22.

When the superconducting bearing device is operated, the superconductor 2 is cooled with a suitable refrigerant circulated through the cooling case 22 and maintained in a superconducting state. As in the case of the first embodiment, the restraining action of the magnetic flux penetrating into the superconductor 2 from the permanent magnet portion 3 and trapped in the superconduct 2 holds the rotatable member 1 and the superconductor 2 opposed to each other with a predetermined spacing provided therebetween and supports the member 1 as levitated above the superconductor 2.

At each end of the permanent magnet portion 3, the magnetism of one of the permanent magnets 4a, 4b, 4c repels that of another magnet of the same polarity, with the result that the magnetic flux extends to a greater extent axially of the rotatable member 1 than in the case where the permanent magnet portion has a single permanent magnet. Consequently, an increased quantity of flux penetrates into the superconductor 2 which is disposed as opposed to the lower end face of the magnet portion 3 for the superconductor 2 to trap the increased quantity of flux. This gives the device a greater load capacity and higher rigidity.

In addition to the superconductor 2, second superconductors 6 may be provided as indicated in broken lines in FIG. 3. These second superconductors 6 are arranged radially outwardly of the periphery of the permanent magnet portion 3 at a distance from and as opposed to the periphery. These superconductors 6 also support the rotatable member 1, consequently giving further enhanced rigidity to the entire bearing device. These superconductors 6 may form a completely annular block or may be segments of an annular block.

FIG. 4 schematically shows the main portion of a fourth superconducting bearing device.

In this device, superconductors 2, 6, 7 are provided as opposed respectively to the lower end face, outer peripheral surface and upper end face of a permanent magnet portion 3 on a rotatable member 1.

FIG. 5 schematically shows the main portion of a fifth superconducting bearing device.

This device has a permanent magnet portion 8 which also comprises a plurality of annular permanent magnets 9a, 9b arranged at a spacing radially of the rotatable member 1 and a nonmagnetic material 10 interposed therebetween. The side portions of each permanent magnet 9a or 9b which are opposite radially of the rotatable member 1 are magnetized to polarities opposite to each other, and the opposed side portions of the adjacent magnets 9a, 9b are magnetized to the same polarity. For example, the inner side portion of the inner magnet 9a has N pole, the outer side portion thereof S pole, the inner side portion of the outer magnet 9b S pole, and the outer side portion thereof N pole. Three or more permanent magnets, when used, are also magnetized similarly.

At the opposed side portions of the adjacent magnets 9a, 9b in this device, the magnetism of one side

portion repels that of the other side portion having the same polarity, with the result that the magnetic flux expands both axially and radially of the rotatable member. This permits an increased quantity of flux to penetrate into the superconductor 2 which is opposed to the lower end face of the permanent magnet portion 8.

In this case, additional superconductors may also be provided as opposed to the outer peripheral surface and the upper end face of the magnet portion 8.

FIG. 6 schematically shows the main portion of a sixth superconducting bearing device.

This device has a permanent magnet portion 11 in the form of an integral assembly and comprising a plurality of annular permanent magnets 12a, 12b arranged at a spacing axially of the rotatable member 1 and a nonmagnetic material 13 interposed therebetween. The side portions of each magnet 12a or 12b which are opposite axially of the rotatable member are magnetized to polarities opposite to each other, and the opposed ends of the adjacent magnets 12a, 12b are magnetized to the same polarity. For example, the upper end of the upper magnet 12a is magnetized as N pole, the lower end thereof as S pole, the upper end of the lower magnet 12b as S pole, and the lower end thereof as N pole. The same is true of the case wherein three or more permanent magnets are used.

At the opposed ends of the adjacnet magnets 12a, 12b of the sixth device, the magnetism of one end repels that of the other end having the same polarity, with the result that the magnetic flux expands both axially and radially of the rotatable member. This permits an increased quantity of flux to penetrate into the superconductor 2 which is opposed to the lower end face of the magnet portion 11.

In this case, additional superconductors may also be provided as opposed to the outer peripheral surface and the upper end face of the permanent magnet portion 11.

FIG. 7 schematically shows the main portion of a seventh superconducting bearing device.

In this device, the superconductor 2 of the fifth device is replaced by a superconductor 6 opposed to the outer peripheral surface of the permanent magnet portion 8.

As already stated with reference to the fifth embodiment, the magnetic flux expands both axially and radially of the rotatable member also in this case, with the result that an increased quantity of flux penetrates into the superconductor 6 which is disposed as opposed to the outer peripheral surface of the magnet portion 8.

FIG. 8 schematically shows the main portion of an eighth superconducting bearing device.

In this device, the superconductor 2 of the sixth device is replaced by a superconductor 6 opposed to the outer peripheral surface of the permanent magnet portion 11.

As already described with reference to the sixth device, the magnetic flux expands both axially and radially of the rotatable member also in this case, with the result that in increased quantity of flux penetrates into the superconductor 6 which is disposed as opposed to the outer peripheral surface of the magnet portion 11.

## Claims

1. A method for setting up a superconducting bearing device including a permanent magnet portion (3, 8, 11) mounted on a rotor (1) having a vertical axis of rotation and a Type II superconductor (2, 6, 7) disposed in the permanent magnet portion's magnetic field, the permanent magnet portion (3, 8, 11) being provided on the rotor (1) so that rotation of the rotor (1) does not alter a magnetic flux's distribution about the axis of rotation of the rotor (1); the method comprises:

   a) first disposing the rotor (1) at position with respect to the Type II superconductor (2, 6, 7) to permit magnetic flux from the permanent magnet to penetrate the Type II superconductor (2); thereafter
   b) moving the Type II superconductor to, and holding the Type II superconductor at a temperature for realizing a Type II superconducting state to pin all the penetrating magnetic flux as it is in the interior of the Type II superconductor (2); and thereafter
   c) removing mechanical support from the rotor.

2. A method according to claim 1 **characterized in** that the rotor 1 is disposed at a position spaced apart from the Type II superconductor (2, 6, 7) by a distance permitting a predetermined quantity of magnetic flux of the permanent magnet portion (3, 8, 11) to penetrate into the Type II superconductor (2, 6, 7).

3. A method according to claim 1 or 2 **characterized in** that the rotor is supported by positioning means in its position prior to and during moving the Type II superconductor to a temperature for realizing a Type II superconducting state and the rotor is released from the positioning means when the Type II superconductor is held at a temperature for realizing a Type II superconducting state.

4. The method according to claim 1, 2 or 3, **characterized in** that the permanent magnet portion (3, 8, 11) is annular in shape and has an axial endface; and the Type II superconductor (2, 7) is positioned opposite the axial endface of the permanent magnet portion (3, 8, 11).

5. A method according to any one of the preceding claims **characterized in** that the permanent magnet portion (3, 8, 11) has a radially outer periphery;

and the Type II superconductor (6) is positioned opposite the radial outer periphery of the permanent magnet portion (3, 8, 11).

6. A method according to claim 4 or 5, **characterized in** that the permanent magnet portion (3, 11) has two axial ends; and the permanent magnet portion has magnetic poles at both of the two axial ends.

7. A method according to claim 4 or 5 **characterized in** that the permanent magnet portion (8) has radially inner and outer sides; and the permanent magnet portion (8) has magnetic poles at the radially inner and outer sides.

8. A method according to any one of the preceding claims **characterized in** that the superconductor is an yttrium type oxide ceramic superconductor.

9. A method according to claim 8, **characterized in** that the yttrium type oxide ceramic superconductor includes normally-conductive particles spread uniformly in the interior thereof, constituting pinning points of the penetrating magnetic flux.

10. The method according to claim 8 or 9, **characterized in** that the yttrium type oxide ceramic superconductor is $YBa_2CU_3O_x$.

11. A method according to any one of the preceding claims **characterized in** that the permanent magnet portion (3, 8) is in the form of an integral assembly and includes a plurality of annular permanent magnets (4a, 4b, 4c; 9a, 9b) arranged at a spacing radially of the rotor (1); and a non-magnetic material (5, 10) interposed therebetween.

12. The method of claim 1, wherein the permanent magnet (8) is in the form of an integrally assembly and includes: a plurality of annular permanent magnets (12a, 12b) arranged at a spacing axially of the rotor (11); and a non-magnetic material (13) interposed therebetween.

FIG. 1

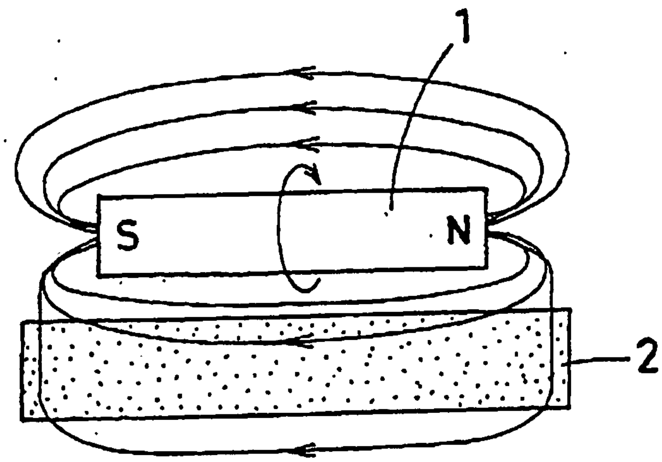


FIG. 2

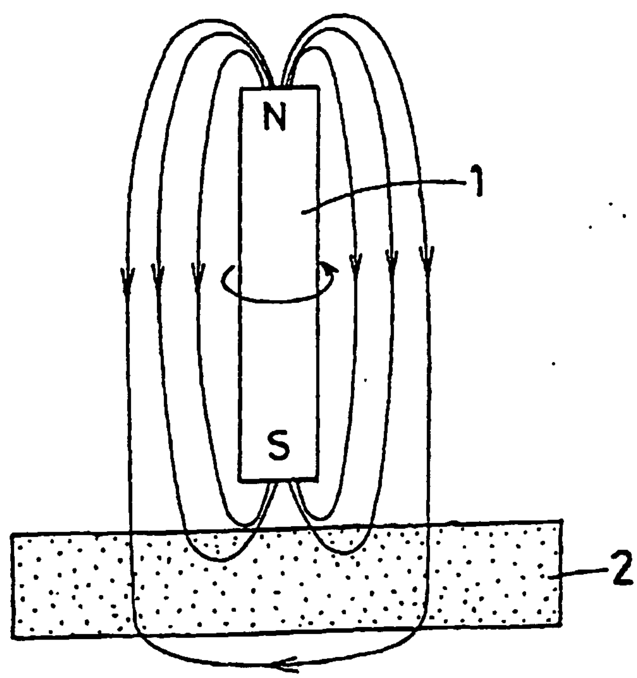

FIG.3

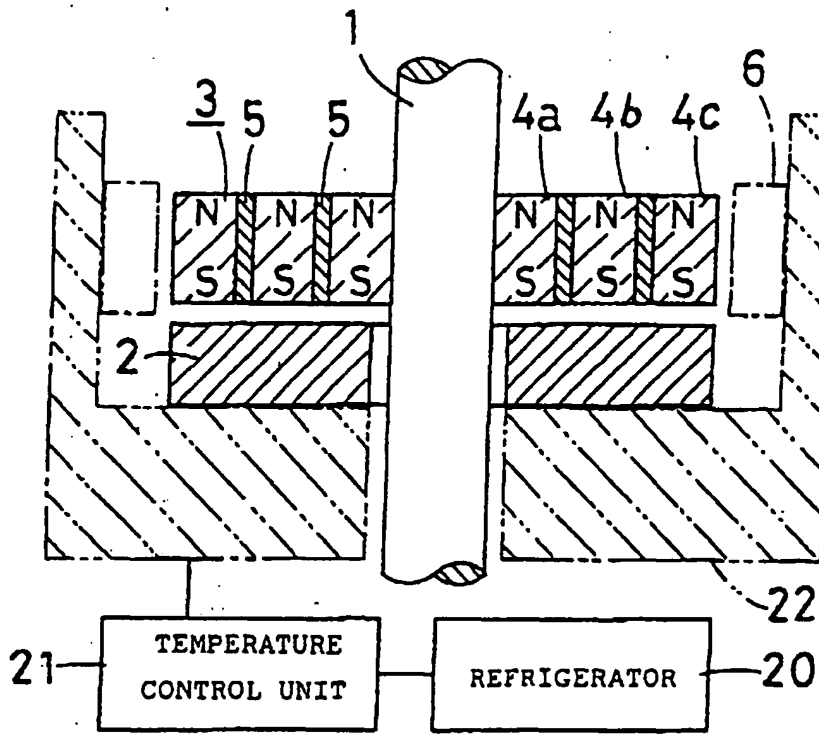
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FIG.4

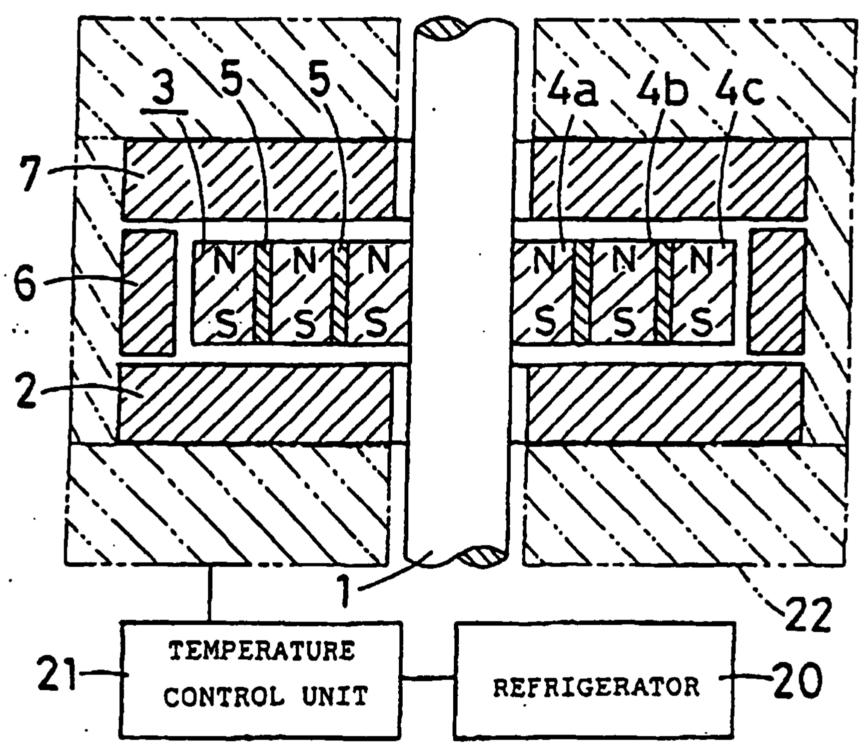
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FIG.5

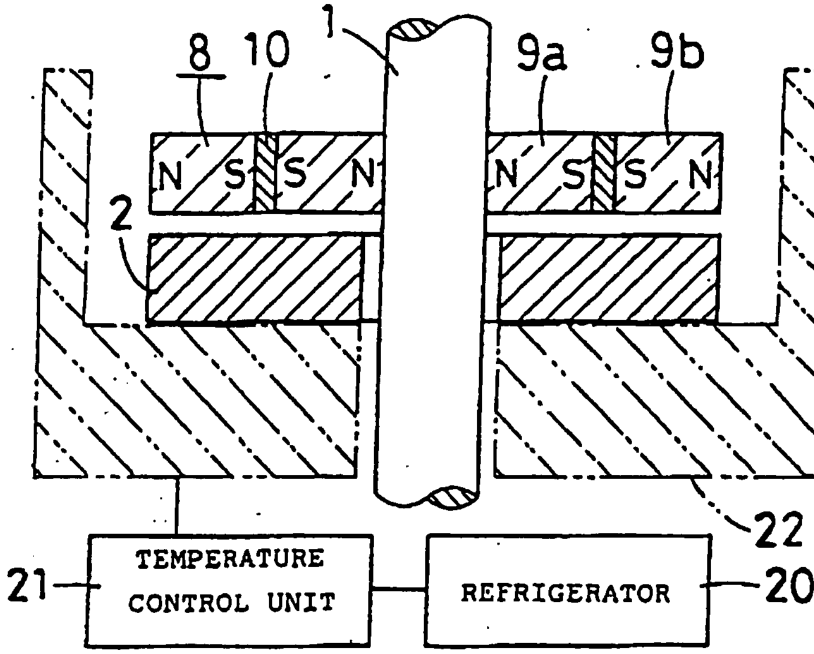
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FIG.6

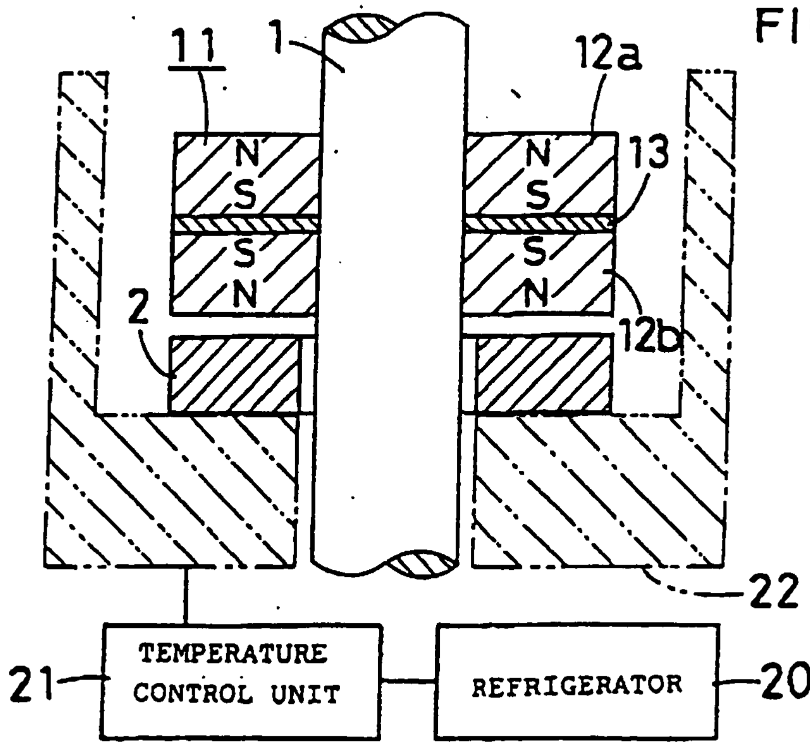
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FIG.7

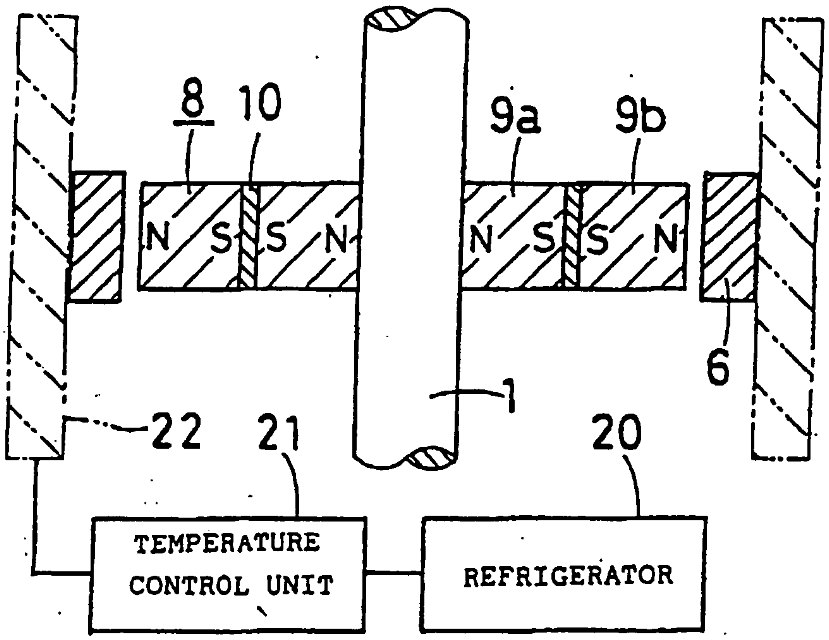
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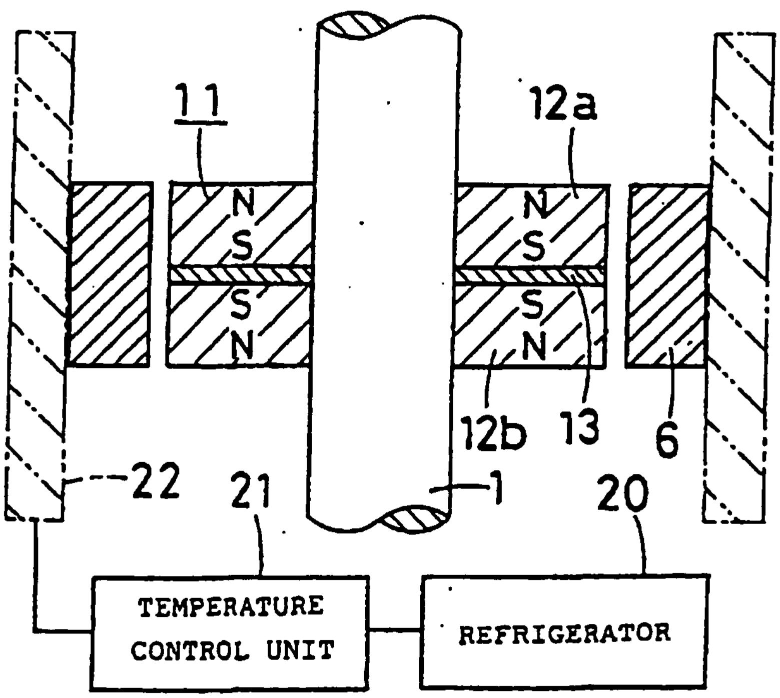
FIG.8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